P2 1080844

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office

November 04, 2003

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY OF THE BELOW IDENTIFIED INTERNATIONAL APPLICATION AS ORIGINALLY FILED AND ANY CORRECTIONS THERETO FROM THE RECORDS OF THE UNITED STATES PATENT AND TRADEMARK OFFICE ACTING AS A RECEIVING OFFICE UNDER THE PATENT COOPERATION TREATY.

APPLICATION NUMBER: ***PCT/US01/26379***
FILING DATE: ***August 24, 2001***

By Authority of the
COMMISSIONER OF PATENTS AND TRADEMARKS

T. Wallace
T. WALLACE
Certifying Officer

TRANSMITTAL LETTER TO THE UNITED STATES RECEIVING OFFICE

PTO-1382 (Rev. 4-1995) (Modified) PCTUS2.FRP /REV03

Date	August 24, 2001
International Application No.	PCT/US 01/26379
Attorney Docket No.	P50-0061 PCT

JC19 Rec'd PCT/PTO 24 AUG 2001

I. Certification under 37 CFR 1.10 (if applicable)

EL449548456US	August 24, 2001
Express Mail mailing number	Date of Deposit

I hereby certify that the application/correspondence attached hereto is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to Assistant Commissioner for Patents, Washington, D.C. 20231.

Sylvia A. Ransom	Sylvia A. Ransom
Signature of person mailing correspondence	Typed or printed name of person mailing correspondence

II. ☒ New International Application

TITLE	NON-PNEUMATIC TIRE	Earliest priority date (Day/Month/Year)

SCREENING DISCLOSURE INFORMATION: In order to assist in screening the accompanying international application for purposes of determining whether a license for foreign transmittal should and could be granted and for other purposes, the following information is supplied. (Note: check as many boxes as apply):

A. ☐ The invention disclosed was **not** made in the United States.

B. ☒ There is no prior U.S. application relating to this invention.

C. ☐ The following prior U.S. application(s) contain subject matter which is related to the invention disclosed in the attached international application. *(NOTE: priority to these applications may or may not be claimed on form PCT/RO/101 (Request) and this listing does not constitute a claim for priority).*

application no.		filed on	
application no.		filed on	

D. ☐ The present international application ☐ is identical ☐ contains less subject matter than that found in the prior U.S. application(s) identified in paragraph C.

E. ☐ The present international application ☐ contains additional subject matter not found in the prior U.S. application(s) identified in paragraph C. above. The additional subject matter is found on pages ______ and ☐ **DOES NOT ALTER** ☐ **MIGHT BE CONSIDERED TO ALTER** the general nature of the invention in a manner which would require the U.S. application to have been made available for inspection by the appropriate defense agencies under 35 U.S.C. 181 and 37 CFR 5.1. See 37 CFR 5.15

III. ☐ A Response to an Invitation from the RO/US. The following document(s) is (are) enclosed:

A. ☐ A Request for An Extension of Time to File a Response

B. ☐ A Power of Attorney (General or Regular)

C. ☐ Replacement pages:

pages		of the request (PCT/RO/101)	pages		of the figures
pages		of the description	pages		of the abstract
pages		of the claims			

D. ☐ Submission of Priority Documents

Priority document		Priority document	

E. ☐ Fees as specified on attached Fee Calculation sheet form PCT/RO/101 annex

IV. ☐ **A Request for Rectification under PCT 91** ☐ **A Petition** ☐ **A Sequence Listing Diskette**

V. ☐ **Other** (please specify):

The person signing this form is the:	☐ Applicant	Martin FARRELL
	☒ Attorney/Agent (Reg. No.) 35,506	Typed name of signer
	☐ Common Representative	Martin Farrell
		Signature

U.S. Department of Commerce: Patent and Trademark Office

HOME COPY

PCT

REQUEST

The undersigned requests that the present international application be processed according to the Patent Cooperation Treaty.

For receiving Office use only

International Application No. PCT/US 01/26379

(24.08.01) 24 AUG 2001

International Filing Date

PCT INTERNATIONAL APPLICATION BOX

Name of receiving Office and "PCT International Application"

Applicant's or agent's file reference *(if desired) (12 characters maximum)*

Box No. I TITLE OF INVENTION
NON-PNEUMATIC TIRE

Box No. II APPLICANT ☐ This person is also inventor

Name and address: ***(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)***

Societe de Technologie Michelin
23 rue Breschet
FR-63000, Clermont-Ferrand
France

Telephone No.
(864) 422-4648

Facsimile No.
(864) 422-3517

Teleprinter No.

Applicant's registration No. with the Office

State *(that is, country)* of nationality:
FR

State *(that is, country)* of residence:
FR

This person is applicant for the purposes of: ☐ all designated States ☐ all designated States except the United States of America ☐ the United States of America only ☒ the States indicated in the Supplemental Box

Box No. III FURTHER APPLICANT(S) AND/OR (FURTHER) INVENTOR(S)

Name and address: ***(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)***

Michelin Recherche et Technique S.A.
Route Louis-Braille 10 et 12
CH-1763, Granges-Paccot
Switzerland

This person is:
☒ applicant only
☐ applicant and inventor
☐ inventor only *(If this check-box is marked, do not fill in below.)*

Applicant's registration No. with the Office

State *(that is, country)* of nationality:
CH

State *(that is, country)* of residence:
CH

This person is applicant for the purposes of: ☐ all designated States ☒ all designated States except the United States of America ☐ the United States of America only ☐ the States indicated in the Supplemental Box

☒ Further applicants and/or (further) inventors are indicated on a continuation sheet.

Box No. IV AGENT OR COMMON REPRESENTATIVE; OR ADDRESS FOR CORRESPONDENCE

The person identified below is hereby/has been appointed to act on behalf of the applicant(s) before the competent International Authorities as: ☒ agent ☐ common representative

Name and address: ***(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country.)***

FARRELL, Martin
Michelin North America, Inc.
Intellectual Property Department
515 Michelin Road
Greenville, South Carolina 29605
United States of America

Telephone No.
(864) 422-4648

Facsimile No.
(864) 422-3517

Teleprinter No.

Agent's registration No. with the Office
35,506

☐ **Address for correspondence:** Mark this check-box where no agent or common representative is/has been appointed and the space above is used instead to indicate a special address to which correspondence should be sent.

PCT/US 01/26379

Continuation of Box No. III FURTHER APPLICANTS AND/OR (FURTHER) INVENTOR(S)

If none of the following sub-boxes is used, this sheet should not to be included in the request.

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

RHYNE, Timothy B.
114 Dellwood Drive
Greenville, South Carolina 29609
United States of America

This person is:

- ☐ applicant only
- ☒ applicant and inventor
- ☐ inventor only *(If this check-box is marked, do not fill in below.)*

Applicant's registration No. with the Office

State *(that is, country)* of nationality: US

State *(that is, country)* of residence: US

This person is applicant for the purposes of: ☐ all designated States ☐ all designated States except the United States of America ☒ the United States of America only ☐ the States indicated in the Supplemental Box

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

THOMPSON, Ronald H.
300 Gilderbrook Road
Greenville, South Carolina 29615
United States of America

This person is:

- ☐ applicant only
- ☒ applicant and inventor
- ☐ inventor only *(If this check-box is marked, do not fill in below.)*

Applicant's registration No. with the Office

State *(that is, country)* of nationality: US

State *(that is, country)* of residence: US

This person is applicant for the purposes of: ☐ all designated States ☐ all designated States except the United States of America ☒ the United States of America only ☐ the States indicated in the Supplemental Box

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

CRON, Steven M.
525 McKinney Road
Simpsonville, South Carolina 29681
United States of America

This person is:

- ☐ applicant only
- ☒ applicant and inventor
- ☐ inventor only *(If this check-box is marked, do not fill in below.)*

Applicant's registration No. with the Office

State *(that is, country)* of nationality: US

State *(that is, country)* of residence: US

This person is applicant for the purposes of: ☐ all designated States ☐ all designated States except the United States of America ☒ the United States of America only ☐ the States indicated in the Supplemental Box

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

DEMINO, Kenneth W.
2816 Ranchwood Drive
Anderson, South Carolina 29621
United States of America

This person is:

- ☐ applicant only
- ☒ applicant and inventor
- ☐ inventor only *(If this check-box is marked, do not fill in below.)*

Applicant's registration No. with the Office

State *(that is, country)* of nationality: US

State *(that is, country)* of residence: US

This person is applicant for the purposes of: ☐ all designated States ☐ all designated States except the United States of America ☒ the United States of America only ☐ the States indicated in the Supplemental Box

☐ Further applicants and/or (further) inventors are indicated on another continuation sheet.

Box No.V **DESIGNATION OF STATES** *Mark the applicable check-boxes below; at least one must be marked.*

The following designations are hereby made under Rule 4.9(a):

Regional Patent

☒ **AP ARIPO Patent:** **GH** Ghana, **GM** Gambia, **KE** Kenya, **LS** Lesotho, **MW** Malawi, **MZ** Mozambique, **SD** Sudan, **SL** Sierra Leone, **SZ** Swaziland, **TZ** United Republic of Tanzania, **UG** Uganda, **ZW** Zimbabwe, and any other State which is a Contracting State of the Harare Protocol and of the PCT

☒ **EA Eurasian Patent:** **AM** Armenia, **AZ** Azerbaijan, **BY** Belarus, **KG** Kyrgyzstan, **KZ** Kazakhstan, **MD** Republic of Moldova, **RU** Russian Federation, **TJ** Tajikistan, **TM** Turkmenistan, and any other State which is a Contracting State of the Eurasian

☒ **EP European Patent:** **AT** Austria, **BE** Belgium, **CH & LI** Switzerland and Liechtenstein, **CY** Cyprus, **DE** Germany, **DK** Denmark, **ES** Spain, **FI** Finland, **FR** France, **GB** United Kingdom, **GR** Greece, **IE** Ireland, **IT** Italy, **LU** Luxembourg, **MC** Monaco, **NL** Netherlands, **PT** Portugal, **SE** Sweden, **TR** Turkey, and any other State which is a Contracting State of the European Patent Convention and of the PCT

☒ **OA OAPI Patent:** **BF** Burkina Faso, **BJ** Benin, **CF** Central African Republic, **CG** Congo, **CI** Côte d'Ivoire, **CM** Cameroon, **GA** Gabon, **GN** Guinea, **GW** Guinea-Bissau, **ML** Mali, **MR** Mauritania, **NE** Niger, **SN** Senegal, **TD** Chad, **TG** Togo, and any other State which is a member State of OAPI and a Contracting State of the PCT *(if other kind of protection or treatment desired, specify on dotted line)* . . . .

National Patent *(if other kind of protection or treatment desired, specify on dotted line):*

☒ **AE** United Arab Emirates
☒ **AG** Antigua and Barbuda
☒ **AL** Albania . . . .
☒ **AM** Armenia . . . .
☒ **AT** Austria . . . .
☒ **AU** Australia . . . .
☒ **AZ** Azerbaijan
☒ **BA** Bosnia and Herzegovina . . . .
☒ **BB** Barbados
☒ **BG** Bulgaria . . . .
☒ **BR** Brazil . . . .
☒ **BY** Belarus . . . .
☒ **BZ** Belize . . . .
☒ **CA** Canada
☒ **CH & LI** Switzerland and Liechtenstein
☒ **CN** China . . . .
☒ **CO** Colombia
☒ **CR** Costa Rica . . . .
☒ **CU** Cuba . . . .
☒ **CZ** Czech Republic . . . .
☒ **DE** Germany . . . .
☒ **DK** Denmark . . . .
☒ **DM** Dominica
☒ **DZ** Algeria . . . .
☒ **EC** Ecuador
☒ **EE** Estonia . . . .
☒ **ES** Spain . . . .
☒ **FI** Finland . . . .
☒ **GB** United Kingdom
☒ **GD** Grenada
☒ **GE** Georgia . . . .
☒ **GH** Ghana . . . .
☒ **GM** Gambia
☒ **HR** Croatia . . . .
☒ **HU** Hungary . . . .
☒ **ID** Indonesia
☒ **IL** Israel . . . .
☒ **IN** India . . . .
☒ **IS** Iceland
☒ **JP** Japan . . . .
☒ **KE** Kenya . . . .
☒ **KG** Kyrgyzsta . . . .
☒ **KP** Democratic People's Republic of Korea . . . .
☒ **KR** Republic of Korea . . . .
☒ **KZ** Kazakhstan . . . .
☒ **LC** Saint Lucia
☒ **LK** Sri Lanka
☒ **LR** Liberia . . . .
☒ **LS** Lesotho . . . .
☒ **LT** Lithuania
☒ **LU** Luxembourg
☒ **LV** Latvia
☒ **MA** Morocco . . . .
☒ **MD** Republic of Moldova . . . .
. . . .
☒ **MG** Madagascar . . . .
☒ **MK** The former Yugoslav Republic of Macedonia . . . .
☒ **MN** Mongolia
☒ **MW** Malawi . . . .
☒ **MX** Mexico . . . .
☒ **MZ** Mozambique
☒ **NO** Norway
☒ **NZ** New Zealand . . . .
☒ **PL** Poland . . . .
☒ **PT** Portugal . . . .
☒ **RO** Romania
☒ **RU** Russian Federation . . . .
. . . .
☒ **SD** Sudan
☒ **SE** Sweden
☒ **SG** Singapore
☒ **SI** Slovenia . . . .
☒ **SK** Slovakia . . . .
☒ **SL** Sierra Leone . . . .
☒ **TJ** Tajikistan . . . .
☒ **TM** Turkmenistan . . . .
☒ **TR** Turkey . . . .
☒ **TT** Trinidad and Tobago . . . .
. . . .
☒ **TZ** United Republic of Tanzania
☒ **UA** Ukraine . . . .
☒ **UG** Uganda . . . .
☒ **US** United States of America . . . .
. . . .
☒ **UZ** Uzbekistan . . . .
☒ **VN** Viet Nam
☒ **YU** Yugoslavia . . . .
☒ **ZA** South Africa . . . .
☒ **ZW** Zimbabwe . . . .

Check-boxes below reserved for designating States which have become party to the PCT after issuance of this sheet:

☒ Equatorial Guinea . . . .
☒ Philippines . . . .
☐ . . . .
☐ . . . .
☐ . . . .
☐ . . . .

Precautionary Designation Statement: In addition to the designations made above, the applicant also makes under Rule 4.9(b) all other designations which would be permitted under the PCT except any designation(s) indicated in the Supplemental Box as being excluded from the scope of this statement. The applicant declares that those additional designations are subject to confirmation and that any designation which is not confirmed before the expiration of 15 months from the priority date is to be regarded as withdrawn by the applicant at the expiration of that time limit. *(Confirmation (including fees) must reach the receiving Office within the 15-month time limit.)*

Supplemental Box *If the Supplemental Box is not used, this sheet should not be included in the request.*

1. *If, in any of the Boxes, except Boxes Nos VIII(i) to (v) for which a special continuation box is provided, **the space is insufficient** to furnish all the information: in such case, write "Continuation of Box No...." (indicate the number of the Box) and furnish the information in the same manner as required according to the captions of the Box in which the space was insufficient, in particular:*

(i) ***if more than two persons are to be indicated as applicants and/or inventors** and no "continuation sheet" is available: in such case, write "Continuation of Box No. III" and indicate for each additional person the same type of information as required in Box No. III. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below;*

(ii) *if, in Box No. II or in any of the sub-boxes of Box No. III, the indication **"the States indicated in the Supplemental Box"** is checked: in such case, write "Continuation of Box No. II" or "Continuation of Box No. III" or "Continuation of Boxes No. II and No. III" (as the case may be), indicate the name of the applicant(s) involved and, next to (each) such name, the State(s) (and/or, where applicable, ARIPO, Eurasian, European or OAPI patent) for the purposes of which the named person is applicant;*

(iii) *if, in Box No. II or in any of the sub-boxes of Box No. III, **the inventor or the inventor/applicant is not inventor for the purposes of all designated States or for the purposes of the United States of America:** in such case, write "Continuation of Box No. II" or "Continuation of Box No. III" or "Continuation of Boxes No. II and No. III" (as the case may be), indicate the name of the inventor(s) and, next to (each) such name, the State(s) (and/or, where applicable, ARIPO, Eurasian, European or OAPI patent) for the purposes of which the named person is inventor;*

(iv) *if, in addition to the agent(s) indicated in Box No. IV, there are **further agents**: in such case, write "Continuation of Box No. IV" and indicate for each further agent the same type of information as required in Box No. IV;*

(v) *if, in Box No. V, the name of any State (or OAPI) is accompanied by the indication **"patent of addition,"** or **"certificate of addition,"** or if, in Box No. V, the name of the United States of America is accompanied by an indication **"continuation"** or **"continuation-in-part"**: in such case, write "Continuation of Box No. V" and the name of each State involved (or OAPI), and after the name of each such State (or OAPI), the number of the parent title or parent application and the date of grant of the parent title or filing of the parent application;*

(vi) *if, in Box No. VI, there are **more than five earlier applications whose priority is claimed**: in such case, write "Continuation of Box No. VI" and indicate for each additional earlier application the same type of information as required in Box No. VI.*

2. *If, with regard to the **precautionary designation statement** contained in Box No. V, the applicant wishes to exclude any State(s) from the scope of that statement: in such case, write "Designation(s) excluded from precautionary designation statement" and indicate the name or two-letter code of each State so excluded.*

Continuation of Box II

Societe de Technologie Michelin is the Applicant for all the designated states except Canada, Mexico and the United States of America.

Box No. VI PRIORITY CLAIM

The priority of the following earlier application(s) is hereby claimed:

Filing date of earlier application *(day/month/year)*	Number of earlier application	Where earlier application is:		
		national application: country	regional application:* regional Office	international application: receiving Office
item (1)				
item (2)				
item (3)				
item (4)				
item (5)				

☐ Further priority claims are indicated in the Supplemental Box.

The receiving Office is requested to prepare and transmit to the International Bureau a certified copy of the earlier application(s) *(only if the earlier application was filed with the Office which for the purposes of this international application is the receiving Office)* identified above as:

☐ all items ☐ item (1) ☐ item (2) ☐ item (3) ☐ item (4) ☐ item (5) ☐ other, see Supplemental Box

* *Where the earlier application is an ARIPO application, indicate at least one country party to the Paris Convention for the Protection of Industrial Property or one Member of the World Trade Organization for which that earlier application was filed (Rule 4.10(b)(ii)):* ....

....

Box No. VII INTERNATIONAL SEARCHING AUTHORITY

Choice of International Searching Authority (ISA) *(if two or more International Searching Authorities are competent to carry out the international search, indicate the Authority chosen; the two-letter code may be used):*

ISA/ EP..

Request to use results of earlier search; reference to that search *(if an earlier search has been carried out by or requested from the International Searching Authority):*

Date *(day/month/year)*   Number   Country (*or regional Office*)

Box No. VIII DECLARATIONS

The following **declarations** are contained in Boxes Nos. VIII (i) to (v) *(mark the applicable check-boxes below and indicate in the right column the number of each type of declaration)*:   Number of declarations

☐	Box No. VIII (i)	Declaration as to the identity of the inventor	:
☐	Box No. VIII (ii)	Declaration as to the applicant's entitlement, as at the international filing date, to apply for and be granted a patent	:
☐	Box No. VIII (iii)	Declaration as to the applicant's entitlement, as at the international filing date, to claim the priority of the earlier application	:
☐	Box No. VIII (iv)	Declaration of inventorship (only for the purposes of the designation of the United States of America)	:
☐	Box No. VIII (v)	Declaration as to non-prejudicial disclosures or exceptions to lack of novelty	:

PCT/US 01/26379

Box No. IX CHECK LIST; LANGUAGE OF FILING

This international application **contains:**

(a) the following number of **sheets in paper form:**

request (including declaration sheets)	:	6
description (excluding sequence listing part)	:	17
claims	:	4
abstract	:	1
drawings	:	9
Sub-total number of sheets	:	37
sequence listing part of description *(actual number of sheets if filed in paper form, whether or not also filed in computer readable form; see (b) below)*	:	
Total number of sheets	:	37

(b) sequence listing part of description filed in **computer readable form**

(i) ☐ only (under Section 801 (a)(i))

(ii) ☐ in addition to being filed in paper form (under Section 801 (a)(ii))

Type and number of carriers (diskette, CD-ROM, CD-R or other) on which the sequence listing part is contained *(additional copies to be indicated under item 9(ii), in right column)*:

....

This international application is **accompanied by** the following item(s) *(mark the applicable check-boxes below and indicate in right column the number of each item)*:

		Number of items
1. ☒ fee calculation sheet	:	1
2. ☒ original separate power of attorney	:	1
3. ☐ original general power of attorney	:	
4. ☒ copy of general power of attorney; reference number, if any:	:	2
5. ☐ statement explaining lack of signature	:	
6. ☐ priority document(s) identified in Box No. VI as item(s):	:	
7. ☐ translation of international application into *(language)*:	:	
8. ☐ separate indications concerning deposited microorganism or other biological material	:	
9. ☐ sequence listing in computer readable form (indicate also type and number of carriers (diskette, CD-ROM, CD-R or other))		
(i) ☐ copy submitted for the purposes of international search under Rule 13*ter* only (and not as part of the international application)	:	
(ii) ☐ *(only where check-box (b)(i) or (b)(ii) is marked in left column)* additional copies including, where applicable, the copy for the purposes of international search under Rule 13*ter*	:	
(iii) ☐ together with relevant statement as to the identity of the copy or copies with the sequence listing part mentioned in left column	:	
10. ☐ other *(specify)*:	:	

Figure of the drawings which should accompany the abstract: 1

Language of filing of the international application: English

Box No. X SIGNATURE OF APPLICANT, AGENT OR COMMON REPRESENTATIVE

Next to each signature, indicate the name of the person signing and the capacity in which the person signs (if such capacity is not obvious from reading the request).

RHYNE, Timothy B. Inventor

THOMPSON, Ronald H. Inventor

24Aug2001

CRON, Steven M. Inventor

Kenneth W. DeMino

DEMINO, Kenneth W. Inventor

FARRELL, Martin Agent

(24.08.01)

For receiving Office use only

1. Date of actual receipt of the purported international application:	JC10 Rec'd PCT/PTO 24 AUG 2001
3. Corrected date of actual receipt due to later but timely received papers or drawings completing the purported international application:	
4. Date of timely receipt of the required corrections under PCT Article 11(2):	
5. International Searching Authority (if two or more are competent): ISA/ EP	6. ☐ Transmittal of search copy delayed until search fee is paid

2. Drawings:

☐ received:

☐ not received:

For International Bureau use only

Date of receipt of the record copy by the International Bureau:

This sheet is not part of and does not count as a sheet of the international application.

PCT

FEE CALCULATION SHEET

Annex to the Request

For receiving Office use only

International Application No. PCT/US 01/26379

(24.08.01) Date stamp of the receiving Office 24 AUG 2001

Applicant's or agent's file reference: **P50-0061 PCT**

Applicant
Societe de Technologie Michelin and Michelin Recherche et Technique S.A.

CALCULATION OF PRESCRIBED FEES

1. TRANSMITTAL FEE . . . . 240.00 [T] — 240
2. SEARCH FEE . . . . 846.00 [S] — 846

International search to be carried out by ISA/EP

(If two or more International Searching Authorities are competent to carry out the international search, indicate the name of the Authority which is chosen to carry out the international search.)

3. INTERNATIONAL FEE

Basic Fee

Where item (b) of Box No. IX applies, enter **Sub-total number of sheets**
Where item (b) of Box No. IX does not apply, enter **Total number of sheets** } 37

[b1] first 30 sheets . . . . 382.00 [b1] — 382

[b2] 7 (number of sheets) x 9.00 (fee per sheet) = 63.00 [b2] — 63

[b3] additional component (only if sequence listing part of description is filed in computer readable form under Section 801(a)(i), or both in that form and on paper, under Section 801(a)(ii)):

400 x ______ (fee per sheet) = ______ [b3]

Add amounts entered at b1, b2 and b3 and enter total at B . . . 445.00 [B] — 445

Designation Fees

The international application contains 113 designations.

6 (number of designation fees payable *(maximum 6)*) x 82.00 (amount of designation fee) = 492.00 [D] — 492

Add amounts entered at B and D and enter total at I . . . . 937.00 [I] — 937

(Applicants from certain States are entitled to a reduction of 75% of the international fee. Where the applicant is (or all applicants are) so entitled, the

4. FEE FOR PRIORITY DOCUMENT *(if applicable)* . . . . 0.00 [P] — 0
5. TOTAL FEES PAYABLE . . . . 2,023.00 TOTAL — 2023

Add amounts entered at T, S, I and P, and enter total in the TOTAL box

☐ The designation fees are not paid at this time.

MODE OF PAYMENT

☒ authorization to charge ☐ postal money order ☐ cash ☐ coupons

☐ cheque ☐ bank draft ☐ revenue stamps ☐ other *(specify)*:

AUTHORIZATION TO CHARGE (OR CREDIT) DEPOSIT ACCOUNT

(This mode of payment may not be available at all receiving Offices)

Receiving Office: RO/ US

☒ Authorization to charge the total fees indicated above.

Deposit Account No.: 13-3085

☒ *(This check-box may be marked only if the conditions for deposit accounts of the receiving Office so permit)* Authorization to charge any deficiency or credit any overpayment in the total fees indicated above.

Date: August 24, 2001

Name: Martin FARRELL

☐ Authorization to charge the fee for priority document.

Signature: Martin Farrell

PCT

PCT/US 01/26379

POWER OF ATTORNEY

(for an international application filed under the Patent Cooperation Treaty)

(PCT Rule 90.4)

The undersigned applicant(s) *(Names should be indicated as they appear in the request)*:

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hereby appoints (appoint) the following person as: ☒ agent ☐ common representative

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to represent the undersigned before

☒ all the competent International Authorities

☐ the International Searching Authority only

☐ the International Preliminary Examining Authority only

in connection with the international application identified below:

Title of the invention: NON-PNEUMATIC TIRE

Applicant's or agent's file reference: P50-0061 PCT

International application number (if already available):

filed with the following Office United States Patent and Trademark Office as receiving Office and to make or receive payments on behalf of the undersigned.

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RHYNE, Timothy B. THOMPSON, Ronald H.

CRON, Steven M. Kenneth W. DeMino DEMINO, Kenneth W.

Date: August 24, 2001

PCT PCT/US 01/26379

GENERAL POWER OF ATTORNEY

(for several international applications filed under the Patent Cooperation Treaty)

(PCT Rule 90.5)

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Societe de Technologie Michelin

Michel RCLLIER
Secretary

Date: May 15 , 2000

PCT/US 01/26379

PCT

GENERAL POWER OF ATTORNEY

(for several international applications filed under the Patent Cooperation Treaty)

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and to make or receive payments on behalf of the undersigned.

Signature(s) *(where there are several persons, each of them must sign; next to each signature, indicate the name of the person signing and the capacity in which the person signs, if such capacity is not obvious from reading this power):*

MICHELIN RECHERCHE ET TECHNIQUE S.A

GALLEY, Paul
Member of the Board

Date: August 9, 1999

ATTESTATION

PCT/US 01/26379

Le notaire **Olivier ANDREY** soussigné, à Fribourg et Estavayer-le-Lac,

atteste par la présente

que Monsieur **Paul GALLEY**, fils de Jules, né le 5 août 1946, de nationalité suisse, marié, domicilié à Villars-sur-Glâne (Suisse), Rte du Bugnon 12, est Membre unique de l'Administration de la société MICHELIN RECHERCHE ET TECHNIQUE S.A., dont le siège est à Granges-Paccot (Canton de Fribourg / Suisse), Route Louis-Braille 10 et 12, qu'il est titulaire de la signature individuelle, ainsi qu'il appert des inscriptions faites au Registre du commerce de la Sarine, à Fribourg

et

que la signature ci-dessous apposée est bien celle de Monsieur Paul Galley.

Granges-Paccot, le 8 juin 1998.

CERTIFICATE

The undersigned, **Olivier ANDREY**, public notary of Fribourg and Estavayer-le-Lac,

hereby certifies

that Mr **Paul GALLEY**, son of Jules, born 5 August 1946, of Swiss nationality, married, residing in Villars-sur-Glâne (Switzerland), Rte du Bugnon 12, is the sole Member of the Management of MICHELIN RECHERCHE ET TECHNIQUE LTD, whose registered office is in Granges-Paccot (Canton of Fribourg / Switzerland), Route Louis-Braille 10 and 12 ; that he is entitled to sign for the company by his sole signature, as entered in the Sarine district Trade Register, in Fribourg

and

that the signature hereafter affixed is that of Mr Paul Galley.

Granges-Paccot, 8 June 1998.

OLIVIER ANDREY NOTAIRE

Paul Galley

Olivier Andrey

Annexe : extrait du registre du commerce de la Sarine, à Fribourg

PCT/US 01/26379

Registre du commerce FRIBOURG **Registre princip.**

Numéro d'ordre	Fiche	Nature juridique	Report du	Date de l'inscription	Date de la radiation	Numéro du dossier
3 6148	1	Société anonyme		29.12.1988		

Réf.	Raison sociale ou nom	Réf.	Siège	Réf.	Domicile — Adresse	Réf.	Date des statuts	Réf.	Succursales
1	~~Michelin Recherche et Technique SA~~		(précéd. à Bâle)	1	~~c/o Michelin Import-export S.A., Eurorésidence, Grand-Places 14A.~~		09.01.1963		
8	Michelin Recherche et Technique S.A. (Michelin Recherche et Technique AG) (Michelin Recherche et Technique Limited)	1	~~Fribourg~~	2	~~Eurorésidence 14A.~~	1	22.12.1988		
		6	Granges-Paccot	6	Route Louis-Braille 10 et 12	6	22.12.1993		
						8	21.6.1996		

Réf	Capital nominal	Capital libéré	Actions, prestations des associés, ressources
1	~~25'000'000.--~~	~~25'000'000.--~~	~~250'000 actions de Fr. 100.-, au porteur~~
8	25'000'000.-	25'000'000.-	2'500'000 actions de Fr. 10.-, nominatives.

Réf.	Apports en nature, reprise de biens, compensation de créances, avantages particuliers, responsabilité, versements supplémentaires
1	22'500'000.--, libérés par compensation de créances.

Réf.	But, observations
1	~~But : promouvoir, coordonner, faciliter et éventuellement financer la recherche fondamentale et la recherche d'application; les études réalisées dand le domaine des droits incorporels et industriels, ainsi que l'utilisation des résultats obtenus pouvant intéresser l'une ou l'autre des sociétés du groupe Michelin. Obtention et gestion de brevets et licences; conseils techniques; prise de participations.~~
1	Administration : un ou plusieurs membres. (Le conseil fixe le mode de signature)
1	Transfert du siège de Bâle)
8	But: promouvoir, coordonner, faciliter et éventuellement financer la recherche fondamentale et la recherche appliquée, les études réalisées dans le domaine des droits incorporels et industriels, ainsi que l'utilisation des résultats obtenus pouvant intéresser l'une ou l'autre des sociétés du groupe Michelin.
8	Convocation: lettre.

Réf.	Organes de publicité, autorité de surveillance (fondation)
1	Feuille Officielle Suisse du Commerce

REGISTRE DU COMMERCE FRIBOURG

NON-PNEUMATIC TIRE

BACKGROUND AND SUMMARY OF THE INVENTION

[01] The invention relates to a non-pneumatic, structurally supported tire. More particularly, the invention relates to a non-pneumatic tire that supports a load with its structural components and has pneumatic tire-like performance capabilities to serve as a replacement for pneumatic tires.

[02] The pneumatic tire has capabilities in load carrying, road shock absorption, and force transmission (accelerating, stopping, and steering) that make it the preferred choice for use on many vehicles, most notably, bicycles, motorcycles, automobiles, and trucks. These capabilities have also been highly advantageous in the development of the automobile and other motor vehicles. Pneumatic tire capabilities in shock absorption are also useful in other applications, for example, in carts carrying sensitive medical or electronic equipment.

[03] Conventional non-pneumatic alternatives, for example, solid tires, spring tires, and cushion tires lack the performance advantages of pneumatic tires. In particular, solid and cushion tires rely on compression of the ground-contacting portion for load support. These types of tires can be heavy and stiff and lack the shock absorbing capability of pneumatic tires. When made more resilient, conventional non-pneumatic tires lack the load support or endurance of pneumatic tires. Accordingly, except in limited situations, known non-pneumatic tires have not found wide use as substitutes for pneumatic tires.

[04] A non-pneumatic tire having performance characteristics similar to those of pneumatic tires would overcome the various deficiencies in the art and would be a welcome improvement.

[05] A structurally supported, non-pneumatic tire in accordance with the invention includes a reinforced annular band that supports the load on the tire and a plurality of web spokes that transmit in tension the load forces between the annular band and a wheel or hub. Accordingly, a tire of the invention supports its load solely through the structural properties and, contrary to the mechanism in pneumatic tires, without support from internal air pressure.

[06] According to an embodiment useful as a tire on a motor vehicle, a structurally supported tire includes a tread portion, a reinforced annular band radially inward of the tread portion, a plurality of web spokes extending transversely across and radially inward from the annular band toward a tire axis, and means for interconnecting the web spokes to a wheel or hub.

[07] In a pneumatic tire, the ground contact pressure and stiffness are a direct result of the inflation pressure, and are interrelated. The tire in accordance with the invention has stiffness properties and a ground contact pressure that are based on the structural components of the tire, and, advantageously, may be specified independent of one another.

[08] The structurally supported tire of the invention does not have a cavity for containing air under pressure, and accordingly, does not need to form a seal with the wheel rim to retain internal air pressure. The structurally supported tire does not, therefore, require a wheel as understood in the pneumatic tire art. For the purposes of the following description, the terms "wheel" and "hub" refer to any device or structure for supporting the tire and mounting to the vehicle axle, and are considered interchangeable herein.

[09] According to the invention, the annular band comprises an elastomeric shear layer, at least a first membrane adhered to the radially inward extent of the elastomeric shear layer, and at least a second membrane adhered to the radially outward extent of the elastomeric shear layer. The membranes have a circumferential tensile modulus of elasticity sufficiently greater than the shear modulus of elasticity of the elastomeric shear layer such that, under an externally applied load, the ground contacting tread portion deforms from essentially a circular shape to a shape conforming with the ground surface while maintaining an essentially constant length of the membranes. Relative displacement of the membranes occurs by shear in the shear layer. Preferably, the membranes comprise superposed layers of essentially inextensible cord reinforcements embedded in an elastomeric coating layer.

[10] The elastomeric shear layer is formed of a material, such as natural or synthetic rubber, polyurethane, foamed rubber and foamed polyurethane, segmented copolyesters and block co-polymers of nylon. Preferably, the shear layer material has a

shear modulus or about 3 MPa to about 20 MPa. The annular band has the ability to bend from a normal circular shape while under load to conform to a contact surface, such as a road surface.

[11] The web spokes act in tension to transmit load forces between the wheel and the annular band, thus, among other functions, supporting the mass of a vehicle. Support forces are generated by tension in the web spokes not connected to the ground-contacting portion of the annular band. The wheel or hub can be said to hang from the upper portion of the tire. Preferably, the web spokes have a high effective radial stiffness in tension and a low effective radial stiffness in compression. The low stiffness in compression allows the web spokes attached to the ground-contacting portion of the annular band to bend for absorbing road shocks and for better conforming the annular band to the irregularities in the road surface.

[12] The web spokes also transmit the forces required for accelerating, stopping, and cornering. The arrangement and orientation of the web spokes can be selected to obtain the desired function. For example, in applications where relatively low circumferential forces are generated, the web spokes can be arranged radially and in parallel with the tire axis of rotation. To provide stiffness in the circumferential direction, web spokes perpendicular to the axis of rotation can be added, alternating with the axis-aligned web spokes. Another alternative is to arrange the web spokes oblique to the tire axis to provide stiffness in both the circumferential and axial directions. Another alternative is to orient the web spokes to be in an alternating oblique arrangement, that is, in a zig-zag pattern when viewed on the equatorial plane.

[13] To facilitate the bending of the web spokes of the ground contacting portion of the tread, the spokes can be curved. Alternatively, the web spokes can be pre-stressed during molding to bend in a particular direction.

[14] According to an embodiment of the invention, a structurally supported resilient tire comprises a ground contacting tread portion, a reinforced annular band radially inward of the tread portion, and a plurality of web spokes extending radially inward from the reinforced annular band, means for interconnecting the plurality of web spokes to a wheel or hub, the reinforced annular band comprising an elastomeric shear layer, at least a first membrane adhered to the radially inward extent of the elastomeric shear

layer and at least a second membrane adhered to the radially outward extent of the elastomeric shear layer.

[15] According to another embodiment, the invention comprises a structurally supported wheel-tire, comprising a reinforced annular band comprising an elastomeric shear layer, at least a first membrane adhered to a radially inward extent of the elastomeric shear layer and at least a second membrane adhered to a radially outward extent of the elastomeric shear layer, wherein each of the membranes has a longitudinal tensile modulus greater than the shear modulus of the shear layer, a tread adhered to a radially outer extent of the reinforced annular band, a plurality of web spokes extending substantially transversely across and radially inward from the reinforced annular band, and a wheel radially inward of the plurality of web spokes and integrated therewith.

BRIEF DESCRIPTION OF THE DRAWINGS

[16] The invention will be better understood through reference to the following description and the appended drawings, in which:

[17] Fig. 1 is a schematic view in the equatorial plane of a tire of the invention under load;

[18] Fig. 2 is a section view of a tire in accordance with the invention taken in the meridian plane;

[19] Fig. 3 is a schematic diagram illustrating the ground reaction forces for a reference homogeneous band not exhibiting shear deformation;

[20] Fig. 4 is a schematic diagram illustrating the ground reaction forces for an annular band in accordance with the invention;

[21] Fig. 5 is a section view of an alternative embodiment of a tire of the invention taken in the meridian plane;

[22] Fig. 6 is a schematic view in the meridian plane of a loaded tire of the invention showing certain reference dimensions to describe the load carrying mechanism;

[23] Fig. 7 is a section view showing an arrangement of web spokes in an X pattern for a tire viewed in the equatorial plane;

[24] Fig. 8 is a view of an alternative arrangement of web spokes in a zig-zag pattern viewed in the equatorial plane;

[25] Fig. 9 is a view of an arrangement of web spokes in an oblique axial pattern viewed radially toward the axis of rotation;

[26] Fig. 10 shows an alternative chevron arrangement of web spokes viewed radially toward the axis of rotation;

[27] Fig. 11 is shows an alternative arrangement of alternating circumferentially- and axially-aligned web spokes viewed radially toward the axis of rotation;

[28] Fig. 12 illustrates schematically counterdeflection stiffness as viewed in the tire equatorial plane;

[29] Fig. 13 illustrates graphically the relationship among contact area, contact pressure and vertical load for a tire in accordance with the invention; and

[30] Fig. 14 illustrates graphically the relationship among contact pressure, vertical stiffness, and counterdeflection stiffness for a tire in accordance with the invention.

DETAILED DESCRIPTION OF THE INVENTION

[31] The following terms are defined as follows for this description:

[32] "Equatorial Plane" means a plane that passes perpendicular to the tire axis of rotation and bisects the tire structure.

[33] "Meridian Plane" means a plane that passes through and includes the axis of rotation of the tire.

[34] "Modulus" of elastomeric materials means the tensile modulus of elasticity at 10% elongation measured per ASTM Standard Test Method D412.

[35] "Modulus" of the membranes means the tensile modulus of elasticity at 1% elongation in the circumferential direction multiplied by the effective thickness of the

membrane. This modulus can be calculated by Equation 1, below, for conventional tire steel belt materials. This modulus is noted with a prime (') designation.

[36] "Shear Modulus" of elastomeric materials means the shear modulus of elasticity and is defined equivalent to one-third the tensile modulus of elasticity as defined above for elastomeric materials.

[37] "Hysteresis" means the dynamic loss tangent (tan Δ) measured at operating strain, temperature, and frequency. One of ordinary skill in the art will understand that the operating conditions differ for particular applications, for example, the different load and speed requirements for golf carts and sports cars, and that the strain, temperature, and frequency are to be specified for the particular application.

[38] A structurally supported resilient tire in accordance with the invention is shown in schematic view in Fig. 1 in the equatorial plane. Structurally supported means that the tire carries a load by its structural components without the support of gas inflation pressure. The structures disclosed for the several variations of a structurally supported resilient tire utilize similar basic components. Reference numerals depicted in the drawings follow a consistent pattern for each variation. The figures are not drawn to scale, and the dimensions of elements have been exaggerated or reduced for clarity of the illustration.

[39] The tire 100 shown in Fig. 1 has a ground contacting tread portion 105, a reinforced annular band 110 disposed radially inward of the tread portion, a plurality of web spokes 150 extending transversely across and radially inward from the annular band, and a mounting band 160 at the radially inner end of the web spokes. The mounting band 160 anchors the tire 100 to a wheel 10 or hub. As used herein "extending transversely" means that the web spokes 150 may be axially aligned, or may be oblique to the tire axis. Further, "extending radially inward" means that the web spokes 150 may lie in a plane radial to the tire axis or may be oblique to the radial plane. In addition, as explained below, a second plurality of web spokes may extend in the equatorial plane.

[40] Referring to Fig. 2, which shows the tire 100 and wheel 10 in section view in the meridian plane, the reinforced annular band 110 comprises an elastomeric shear layer 120, a first membrane 130 adhered to the radially innermost extent of the elastomeric

shear layer 120, and a second membrane 140 adhered to the radially outermost extent of the elastomeric shear layer 120. The membranes 130 and 140 have a tensile stiffness that is greater than the shear stiffness of the shear layer 120 so that the reinforced annular band 110 undergoes shear deformation under load.

[41] The reinforced annular band 110 supports loads on the tire. As indicated in Fig. 1, a load L placed on the tire axis of rotation X is transmitted by tension in the web spokes 150 to the annular band 110. The annular band 110 acts in a manner similar to an arch and provides a circumferential compression stiffness and a longitudinal bending stiffness in the tire equatorial plane sufficiently high to act as a load-supporting member. Under load, the annular band deforms in contact area C with the ground surface through a mechanism including shear deformation of the band. The ability to deform with shear provides a compliant ground contact area C that acts similar to that of a pneumatic tire, with similar advantageous results.

[42] Referring to Figs. 3 and 4, the advantage of the shear mechanism of the annular band 110 of the invention may be understood by comparison to a rigid annular band 122 comprised of a homogeneous material, for example, a metallic ring, that does not allow for more than insignificant shear deformation under load. In the rigid annular band 122 of Fig. 3, the pressure distribution satisfying the equilibrium force and bending moment requirements is made up of a pair of concentrated forces F located at each end of the contact area, one end of which is shown in Fig. 3. By contrast, if the annular band comprises a structure in accordance with the invention as shown in Fig. 4 of shear layer 120, inner reinforcement 130, and outer reinforcement 140, which prescribes shear deformation, the resulting pressure distribution S on the contact region is substantially uniform.

[43] The beneficial result of the annular band in accordance with the invention is a more uniform ground contact pressure S throughout the length of the contact area, which is similar to a pneumatic tire and improves the tire function over other non-pneumatic tires.

[44] In typical solid and cushion tires, the load is supported by compression of the tire structure in the contact area, and load capacity is limited by the amount and type of material present in the contact area. In certain types of spring tires, a rigid outer ring

supports the load on the tire and is connected to the hub or wheel by resilient spring members. However, a rigid ring does not have a shear mechanism, and thus, as explained above, a rigid ring has concentrated ground reaction forces at the ends of the contact area, which affects the ability of the tire to transmit forces to the ground and to absorb ground shocks.

[45] The shear layer 120 comprises a layer of elastomeric material having a shear modulus of about 3 MPa to about 20 MPa. Materials believed to be suitable for use in the shear layer 120 include natural and synthetic rubbers, polyurethanes, foamed rubbers and polyurethanes, segmented copolyesters, and block co-polymers of nylon. Repeated deformation of the shear layer 120 during rolling under load causes hysteretic losses leading to heat buildup in the tire. Thus, hysteresis of the shear layer should be specified to maintain an operating temperature below the allowable operating temperature for the materials used. For conventional tire materials (e.g., rubber), for example, the hysteresis of the shear layer should be specified to generate a temperature below about 130°C for tires in continuous use.

[46] The tread portion 105 may have no grooves or may have a plurality of longitudinally oriented tread grooves 107 forming essentially longitudinal tread ribs 109 therebetween, as in the illustrative example of Fig. 2. In addition, the tread 105 is shown as being flat from edge to edge. This will be suitable for automobiles and other similar vehicle, but rounded treads may be used for bicycles, motorcycles and other two-wheeled vehicles. Any suitable tread sculpture may be used as is known to those of skill in the art.

[47] According to a preferred embodiment, the first 130 and second 140 membranes comprise essentially inextensible cord reinforcements embedded in an elastomeric coating. For a tire constructed of elastomeric materials, membranes 130 and 140 are adhered to the shear layer 120 by the cured elastomeric materials. It is within the scope of the invention for membranes 130 and 140 to be adhered to the shear layer 120 by any suitable method of chemical or adhesive bonding or mechanical fixation.

[48] The reinforcing elements in the membranes 130, 140 may be any of several materials suitable for use as tire belt reinforcements in conventional tires such as monofilaments or cords of steel, aramid or other high modulus textiles. For the

illustrative tires described herein, the reinforcements are steel cords, each consisting of four wires of 0.28 mm diameter (4x0.28).

[49] According to a preferred embodiment, the first membrane includes two reinforced layers 131 and 132 and the second membrane 140 also includes two reinforced layers 141 and 142.

[50] Although the variations of the invention disclosed herein have cord reinforced layers for each of the membranes, any suitable material may be employed for the membranes which meets the requirements, described below, for the tensile stiffness, bending stiffness, and compressive buckling resistance properties required of the annular band. That is to say, the membrane structure may be any of several alternatives such as a homogeneous material (e.g., thin metal sheet), a fiber reinforced matrix, or a layer having discrete reinforcing elements.

[51] In a first preferred embodiment, the first membrane 130 layers 131 and 132 have essentially parallel cords oriented at an angle of about 10° to about 45° relative to the tire equatorial plane. The cords of the respective layers have an opposite orientation. Similarly for the second membrane 140, layers 141 and 142 have essentially parallel cords oriented at angles between 10° and 45° relative to the equatorial plane. It is not required, however, for the cords of the layer pairs in a membrane to be oriented at mutually equal and opposite angles. For example, it may be desirable for the cords of the layer pairs to be asymmetric relative to the tire equatorial plane.

[52] According to another embodiment, the cords of at least one layer of the membranes can be at or near 0° to the equatorial plane for increased tensile stiffness of the membrane.

[53] The cords of each of the layers 131, 132 and 141, 142 are embedded in an elastomeric coating layer typically having a shear modulus of about 3 to 20 MPa. It is preferred that the shear modulus of the coating layers be substantially equal to the shear modulus of the shear layer 120 to insure that deformation of the annular band is primarily by shear deformation within shear layer 120.

[54] The relationship between the shear modulus G of the elastomeric shear layer 120 and the effective longitudinal tensile modulus $E'_{membrane}$ of the membranes 130 and 140 controls the deformation of the annular band under an applied load. The effective

tensile modulus $E'_{membrane}$ of the membrane using conventional tire belt materials and with membrane reinforcing cords oriented to at least 10° to the equatorial plane can be estimated by the following:

$$E'_{MEMBRANE} = (2D+t)\frac{E_{RUBBER}}{2(1-\nu^2)}\left[\left(\frac{P}{P-D}\right)\frac{2-(1+\nu)SIN^2(2\alpha)}{SIN^4\alpha}+\left(\frac{t}{D}\right)\frac{1}{TAN^2\alpha}\left(\frac{1}{TAN^2\alpha}-\nu\right)\right] \quad (1)$$

[56] Where, E_{rubber} = Tensile modulus of the elastomeric coating material; P = Cord pace (cord centerline spacing) measured perpendicular to the cord direction; D = Cord diameter; ν = Poisson's ratio for the elastomeric coating material; α = Cord angle with respect to the equatorial plan; and, t = Rubber thickness between cables in adjacent layers.

[57] For a shear layer membrane in which the reinforcing cords are oriented at less than 10° to the equatorial plane, the following can be used to estimate the tensile modulus of the membrane $E'_{membrane}$:

[58] $$E'_{membrane} = E_{cable} * V * t_{membrane} \quad (2)$$

[59] where, E_{cable} is the modulus of the cable, V is the volume fraction of the cable in the membrane, and $t_{membrane}$ is the thickness of the membrane.

[60] For membranes comprising a homogeneous material or a fiber or other material reinforced matrix, the modulus is the modulus of the material or matrix.

[61] Note that $E'_{membrane}$ is the elastic modulus of the membrane times the effective thickness of the membrane. When the ratio $E'_{membrane}/G$ is relatively low, deformation of the annular band under load approximates that of the homogeneous band and produces a non-uniform ground contact pressure as shown in Fig. 3. On the other hand, when the ratio $E'_{membrane}/G$ is sufficiently high, deformation of the annular band under load is essentially by shear deformation of the shear layer with little longitudinal extension or compression of the membranes. Accordingly, ground contact pressure is substantially uniform as in the example shown in Fig. 4.

[62] According to the invention, the ratio of the longitudinal tensile modulus of the membrane $E'_{membrane}$ to the shear modulus G of the shear layer is at least about 100:1, and preferably at least about 1000:1.

[63] The tire shown in Fig. 2 has a flat transverse profile for the tread portion 105, first membrane 130 and second membrane 140. The strains in the portion of the annular band in the contact region C (Fig. 1) will be compressive for the second membrane 140. As the vertical deflection of the tire increases, the contact length can increase such that the compressive stress in second membrane 140 exceeds the critical buckling stress, and a longitudinal buckling of the membrane occurs. This buckling phenomenon causes a longitudinally extending section of the contact region to have reduced contact pressure. A more uniform ground contact pressure throughout the length of the ground contacting region is obtained when buckling of the membrane is avoided. A membrane having a curved transverse section will better resist buckling in the contact area and is preferred when buckling under load is a concern.

[64] A variation of the tire of the invention is shown in Fig. 5 wherein tire 300 has an undulated second membrane 340 having an amplitude of undulation in the radial direction and a wavelength of undulation in the axial direction. The amplitude of undulation is defined as the difference between the maximum and minimum radial extents of the membrane 340. The wavelength of undulation is defined as the axial distance between successive radial maxima of the membrane 340. The undulated second membrane 340 resists buckling due to compression in the contact zone like an arcuate membrane described above. Deforming the second membrane 340 from essentially a circular shape to a flat shape by an externally applied load occurs without longitudinal buckling of the second membrane and maintains an essentially uniform ground contact pressure of the ground contacting tread portion throughout the length of the ground contacting region. Thus, it is possible for tire 300 to have a second membrane 340 whose transverse radius of curvature may be specified to optimize ground contact stresses independent of its resistance to buckling. Preferably, second membrane 340 has two to five cycles of undulation, and has a wavelength of undulation of about 20% to about 50% of the rolling tread width of the tread portion 310. The amplitude of undulation is preferably between about 20% and 50% of the maximum shear layer 320 thickness and may be a constant or variable amplitude.

[65] When the previously stated conditions for longitudinal tensile modulus $E'_{membrane}$ of the membranes and the shear modulus G of the shear layer are met and the annular band deforms substantially by shear in the shear layer, an advantageous relation is

created allowing one to specify the values of shear modulus G and shear layer thickness h for a given application:

$$P_{eff}{}^*R \approx G^*h \tag{3}$$

[66] Where, P_{eff} = Ground contact pressure; G = Shear modulus of layer 120 ; h = Thickness of layer 120; and R = Radial position of the second membrane relative to the axis of rotation.

[67] P_{eff} and R are design parameters chosen according to the intended use of the tire. Equation 3 suggests that the product of the shear modulus of elasticity of the shear layer times a radial thickness of the shear layer is approximately equal to a product of ground contact pressure times a radial position of the outermost extent of the second membrane. Fig. 13 graphically illustrates this relationship over a broad range of contact pressures and can be used to estimate the shear layer characteristics for many different applications.

[68] Referring to Fig. 6, the web spokes 150 are substantially sheet-like elements having a length N in the radial direction, a width W in the axial direction corresponding generally to the axial width of the annular band 110, and a thickness perpendicular to the other dimensions. The thickness is much less than either the length N or the width W, and is preferably about 1% to 5% of the radius R of the tire, which allows a web spoke to buckle when under compression, as shown in Fig. 1. Thinner web spokes will bend in the contact area with substantially no compressive resistance, that is, without supplying more than an insignificant compressive force to load bearing. As the thickness of the web spokes increases, the web spokes may provide some compressive load bearing force in the ground contact area. The predominant load transmitting action of the web spokes as a whole, however, is tension. The particular web spoke thickness may be selected to meet the specific requirements of the vehicle.

[69] According to a presently preferred embodiment, the web spokes 150 are formed of a material having high tensile modulus of about 10 to 100 MPa. The web spokes may be reinforced if desired. The web spoke material should also exhibit elastic behavior to return to original length after being strained to 30%, and to exhibit constant stress when the web spoke material is strained to 4%. Further, it is desirable to have a material with a tan Δ of not more than 0.1 at the relevant operating conditions. For

example, commercially available rubber or polyurethane materials can be identified which meet these requirements. The inventors have found that Vibrathane B836 brand urethane from the Uniroyal Chemical division of Crompton Corporation of Middlebury, Connecticut has been suitable for the web spokes.

[70] Referring to Fig. 2, in one embodiment, the web spokes 150 are interconnected by a radially inner mounting band 160, which encircles the wheel or hub 10 to mount the tire. An interface band 170 interconnects the web spokes 150 at their radially outer ends. The interface band 170 connects the web spokes 150 to the annular band 110. For convenience, the web spokes, the mounting band 160, and the interface band 170 may be molded from a single material as a unit.

[71] Alternatively, depending on the construction materials and process for the annular band 110 and hub or wheel 10, a separate mounting band 160 or interface band 170 may be eliminated and the web spokes molded or formed to directly adhere to the annular band and wheel. For example, if either of the annular band or the wheel or hub is formed with the same or compatible materials, the tire could be manufactured with one step forming or molding the web spokes integrally with the annular band or wheel, in which case, the mounting band 160 and/or interface band 170 are integrally formed as part of the wheel or annular band. Further, the web spokes 150 could be mechanically attached to the wheel, for example, by providing an enlarged portion on the inner end of each web spoke that engages a slot in a wheel.

[72] The manner in which a tire of the invention supports an applied load may be understood by reference to Figs. 1 and 6. The region A of the annular band 110, that is, the portion not in ground contact, acts like an arch and the web spokes 150 are in tension T. The load L on the tire, transmitted from the vehicle (not shown) to the hub or wheel 10 essentially hangs from the arch of region A. The web spokes in the transition region B and contact region C are not in tension. According to a preferred embodiment, the web spokes are relatively thin and do not provide more than insignificant vertical load bearing force. As the tire rotates, of course, the specific portion of the annular band 110 acting as an arch continually changes, however, the concept of an arch is useful for understanding the mechanism.

[73] Substantially purely tensile load support is obtained by having a web spoke that has high stiffness in tension but very low stiffness in compression. To facilitate buckling in the ground contact region, the web spokes may be curved. Alternatively, the web spokes can be molded with a curvature and straightened by thermal shrinkage during cooling to provide a predisposition to buckling.

[74] The web spokes 150 should resist torsion between the annular band 110 and the wheel 10, for example, when torque is applied to the wheels. In addition, the web spokes 150 should resist lateral deflection when, for example, in turning or cornering. As will be understood, web spokes 150 that lie in the radial-axial plane, that is, are aligned with both the radial and axial directions, will have high resistance to axially directed forces, but, particularly if elongated in the radial direction, may have difficulty resisting torque in the circumferential direction. For certain vehicles and applications, for example, those producing relatively low acceleration forces, a web spoke package having relatively short spokes aligned with the radial direction will be suitable.

[75] For applications where high torque is expected, one of the arrangements such as those illustrated in Figs. 7-9 may be more suitable. In Fig. 7, the web spokes 150 are oriented in a repeating X pattern as seen in the axial direction, with pairs of spokes forming the X joined at their centers. In Fig. 8, the web spokes are oriented in a zig-zag pattern relative to the radial direction. The web spokes in Fig. 9 are oriented with adjacent web spokes oppositely oriented relative to the axial direction in a zigzag pattern. In these variations, the orientations provide a force-resisting component in both the radial and the circumferential directions, thus adding resistance to torque, while retaining radial and lateral force-resisting components. The angle of orientation may be selected depending on the number of web spokes used and the spacing between adjacent web spokes.

[76] Other alternative arrangements may be used. As shown in Fig. 10, the web spokes may be arranged in a chevron or v-pattern as viewed in the radial direction. Another alternative is to alternate the orientation of adjacent web spokes between axially aligned and circumferentially aligned as shown in Fig. 11. These alternatives may be less preferred, however, because of difficulties in accommodating bending of the web spokes in the contact region.

[77] The various arrangements of the web spokes allow the vertical, lateral, and torsional stiffness of the tire to be tuned independent of the contact pressure and of each other.

[78] Vertical stiffness relates to the ability of the tire to resist deflection when under load. Vertical stiffness of the tire is strongly influenced by the reaction to the load of the portion of the tire not in contact with the ground, the "counterdeflection" of the tire. Fig. 12 illustrates this phenomenon in exaggerated scale. When the tire is under a load L, it deflects an amount f and the portion in ground contact conforms to the ground surface to form a ground contact area C. Note that for the purposes of this description the frame of reference in Fig. 12 maintains the tire axis X at a constant location and moves the ground upward toward the axis. The tire is a resilient body, and accordingly, vertical deflection f is proportional to the load L, from which the vertical stiffness K_v of the tire may be derived. Because the annular band 110 (shown schematically) constrained by the membranes (not illustrated) seeks to maintain a constant length to conserve membrane length, the portion of the tire not in ground contact shifts, or counterdeflects, away from the contact area C, as indicated by the broken lines in the figure. The counterdeflection amount λ is also proportional to the load L, and the counterdeflection stiffness K_λ may thus be obtained. Counterdeflection stiffness K_λ relates primarily to the circumferential compressive stiffness and way that the web spokes not in ground contact bear load. To a lesser extent the transverse and longitudinal bending of the annular band are involved.

[79] Counterdeflection can be measured directly by placing a tire under a load F with the axis fixed and measuring both deflection f of the tire in the contact area and the deflection of the tread surface opposite the contact area. Counterdeflection stiffness is then determined by dividing the load F by the counterdeflection amount λ.

[80] In practice, counterdeflection stiffness K_λ substantially controls the vertical stiffness of the tire, and accordingly, the deflection under load of the wheel axis of a tire. Counterdeflection stiffness K_λ determines the length of the contact area, as may be seen in Figure 12. Low counterdeflection stiffness allows the annular band 110 to move vertically under load, and thus reduces the load capacity at that deflection.

Accordingly, a tire having high counterdeflection stiffness has relatively less counterdeflection and a longer contact area.

[81] Fig. 14 shows graphically an approximated relationship between counterdeflection stiffness K_λ and the vertical stiffness of the tire. Fig. 14 demonstrates the independence of vertical stiffness and contact pressure available with this invention, which allows design flexibility not available in pneumatic tires. A deflated pneumatic tire has typically a counterdeflection stiffness per unit contact area width of less than 0.1 DaN/mm^2. A tire in accordance with the invention, by contrast, can be designed to have a counterdeflection stiffness per unit contact area width ranging above 0.1 DaN/mm^2.

[82] Advantageously, the starting design parameters for any proposed application can be selected using Fig. 14 combined with Fig. 13. Once the contact pressure, vertical load, and contact area are selected using Fig. 13, the vertical stiffness characteristics for the tire may be determined using Fig. 14. With an approximate desired value for counterdeflection stiffness K_λ obtained from Fig. 13, the designer would then use available analytical tools, finite element analysis, for example, to specify the structure to achieve this stiffness. Further work, including building and testing tires would confirm the design parameters.

[83] For example, to design a tire intended for passenger car use, the designer may select a design contact pressure P_{eff} of 1.5 to 2.5 DaN/cm^2 and a tire size in which the radius R is about 335 mm. By multiplying these values, a "shear layer factor" of 50.25 to 83.75 DaN/cm may be determined, which can be used to specify the shear layer material thickness and shear modulus. In this case, with a shear modulus in the range of about 3 MPa to about 10 MPa, the thickness h of the shear layer is at least 5 mm and preferably is between about 10 mm to about 20 mm.

[84] Further, according to the invention, the ground contact pressure and stiffness of the tire are independent of one another, in contrast to a pneumatic tire in which both are related to the inflation pressure. Thus, a tire could be designed for high contact pressure P, but relatively low stiffness. This may be advantageous in producing a tire with low mass and rolling resistance, while retaining load bearing capability.

[85] Counterdeflection stiffness K_λ can be modified in a number of ways. Some of the design parameters used to adjust this stiffness include the web spoke modulus,

web spoke length, web spoke curvature, web thickness, the compressive modulus of the annular band membranes, the thickness of the shear layer, the tire diameter, and the width of the annular band.

[86] Vertical stiffness can be adjusted to optimize the load carrying capability of a given tire. Alternatively, vertical stiffness can be adjusted to provide an annular band of reduced thickness for reduced contact pressure or tire mass while maintaining a desired level of vertical stiffness.

[87] The vertical stiffness of the tire of the invention is also influenced by the effect of centripetal forces on the annular band and sidewall portions. As the speed of a rolling tire increases, centripetal forces develop. In conventional radial tires, centripetal forces can increase tire operating temperature. The tire of the invention, in contrast, obtains an unexpected beneficial result from these same forces. When the tire of the invention rotates under an applied load, centripetal forces cause the annular band to tend to expand circumferentially and induce an additional tension in the web spokes. The radially stiff web spokes for the extent of the tire out of contact (region "A" of Fig 1) resist these centripetal forces. This produces a net upward resultant force which acts to increase the effective vertical stiffness of the tire and to reduce radial deflection of the tire relative to the static, non-rotating condition. This result is obtained to a significant degree when the ratio of the longitudinal stiffness of the band in the tire equatorial plane ($2\cdot E'_{membrane}$) to the effective stiffness of the web spoke portion in tension is less than 100:1.

[88] Applicants understand that many other variations are apparent to one of ordinary skill in the art from a reading of the above specification. These variations and other variations are within the spirit and scope of the instant invention as defined by the following appended claims.

What is claimed is:

1. A structurally supported tire comprising:

a reinforced annular band comprising an elastomeric shear layer, at least a first membrane adhered to a radially inward extent of the elastomeric shear layer and at least a second membrane adhered to a radially outward extent of the elastomeric shear layer, wherein each of the membranes has a longitudinal tensile modulus greater than a shear modulus of the shear layer;

a plurality of web spokes extending transversely across and radially inward from the reinforced annular band; and

means for interconnecting the plurality of web spokes with a wheel.

2. The tire according to claim 1, further comprising a tread portion disposed on a radially outer extent of the reinforced annular band.

3. The tire according to claim 1, wherein said means for interconnecting the plurality of web spokes with a wheel comprises a mounting band mutually interconnecting the radially inner ends of the web spokes.

4. The tire according to claim 1, wherein said means for interconnecting the plurality of web spokes with a wheel comprises an enlarged end portion on each of said web spokes adapted to fit in an engaging slot in a wheel.

5. The tire according to claim 1, wherein the plurality of web spokes further comprises a radially outer band mutually interconnecting radially outer ends of the web spokes.

6. The tire according to claim 1, wherein each web spoke is oriented parallel to the axial direction.

7. The tire according to claim 1, wherein each web spoke is oriented oblique to the axial direction.

8. The tire according to claim 6, wherein mutually adjacent web spokes are oriented at opposite oblique angles to the axial direction.

9. The tire according to claim 1, wherein mutually adjacent web spokes are oriented at opposite oblique angles to the radial direction forming a zig-zag in the equatorial plane.

10. The tire according to claim 1, wherein the plurality of web spokes are oriented in crossed pairs forming a repeating X-pattern in the equatorial plane.

11. The tire according to claim 1, wherein the web spokes have a curvature in the equatorial plane to facilitate bending when under compression in the radial direction.

12. The tire according to claim 1, wherein a first plurality of web spokes is oriented parallel to the axial direction and a second plurality of web spokes is oriented perpendicular to the axial direction.

13. The tire according to claim 1, wherein each web spoke has a thickness that is not more than about 5% of a radius of the tire.

14. The tire according to claim 1, wherein a ratio of the longitudinal tensile modulus of one of the membranes to the shear modulus of the shear layer is at least about 100:1.

15. The tire according to claim 14, wherein the ratio of the longitudinal tensile modulus of one of the membranes to the shear modulus of the shear layer is at least about 1000:1.

16. The tire according to claim 1, wherein a product of the shear modulus of elasticity of the shear layer times a radial thickness of the shear layer is approximately equal to a product of a tire ground contact pressure times a radial position of the outermost extent of the second membrane.

17. The tire according to claim 1, wherein the elastomeric shear layer has a shear modulus of elasticity of about 3 MPa to about 20 MPa.

18. The tire according to claim 1, wherein each of the at least first and second membranes comprise layers of essentially inextensible cord reinforcements embedded in an elastomeric coating layer having a shear modulus of elasticity at least equal to the shear modulus of elasticity of the shear layer.

19. The tire according to claim 18, wherein the cord reinforcements of the first and second membranes form an angle with the tire circumferential direction of between about 10° and 45°.

20. The tire according to claim 1, wherein the second membrane has an arcuate transverse profile having a transverse radius of curvature less than a transverse radius of curvature of a radially outermost surface of the tread portion.

21. The tire according to claim 1 wherein the second membrane is undulated having an amplitude of undulation in the radial direction and a wavelength of undulation in the axial direction.

22. The tire according to claim 1, wherein the first and second membranes are formed of one of a homogeneous material, a fiber reinforced matrix, and a layer having discrete reinforcing elements

23. A structurally supported wheel-tire, comprising:

a reinforced annular band comprising an elastomeric shear layer, at least a first membrane adhered to a radially inward extent of the elastomeric shear layer and at least a second membrane adhered to a radially outward extent of the elastomeric shear layer, wherein each of the membranes has a longitudinal tensile modulus greater than the shear modulus of the shear layer;

a tread adhered to a radially outer extent of the reinforced annular band;

a plurality of web spokes extending substantially transversely across and radially inward from the reinforced annular band; and

a wheel radially inward of the plurality of web spokes and interconnected therewith.

24. The wheel-tire according to claim 23, wherein the wheel and the plurality of web spokes are an integrally molded unit.

25. The wheel-tire according to claim 23, wherein each of the plurality of web spokes is mechanically interconnected to the wheel.

26. The wheel-tire according to claim 23, wherein the plurality of web spokes are interconnected by a mounting band which is adhered to the wheel.

ABSTRACT

A structurally supported tire includes a ground contacting tread portion, a reinforced annular band disposed radially inward of the tread portion, and a plurality of web spokes extending transversely across and radially inward from the reinforced annular band and anchored in a wheel or hub. The reinforced annular band comprises an elastomeric shear layer, at least a first membrane adhered to the radially inward extent of the elastomeric shear layer and at least a second membrane adhered to the radially outward extent of the elastomeric shear layer. Each of the membranes has a longitudinal tensile modulus sufficiently greater than the shear modulus of the shear layer so that when under load the ground contacting portion of the tire deforms to a flat contact region through shear strain in the shear layer while maintaining constant the length of the membranes, the web spokes transmitting load forces between the annular band and the hub through tension in the web spokes not connected to the ground contacting portion of the tire.

Fig. 1

Fig. 1

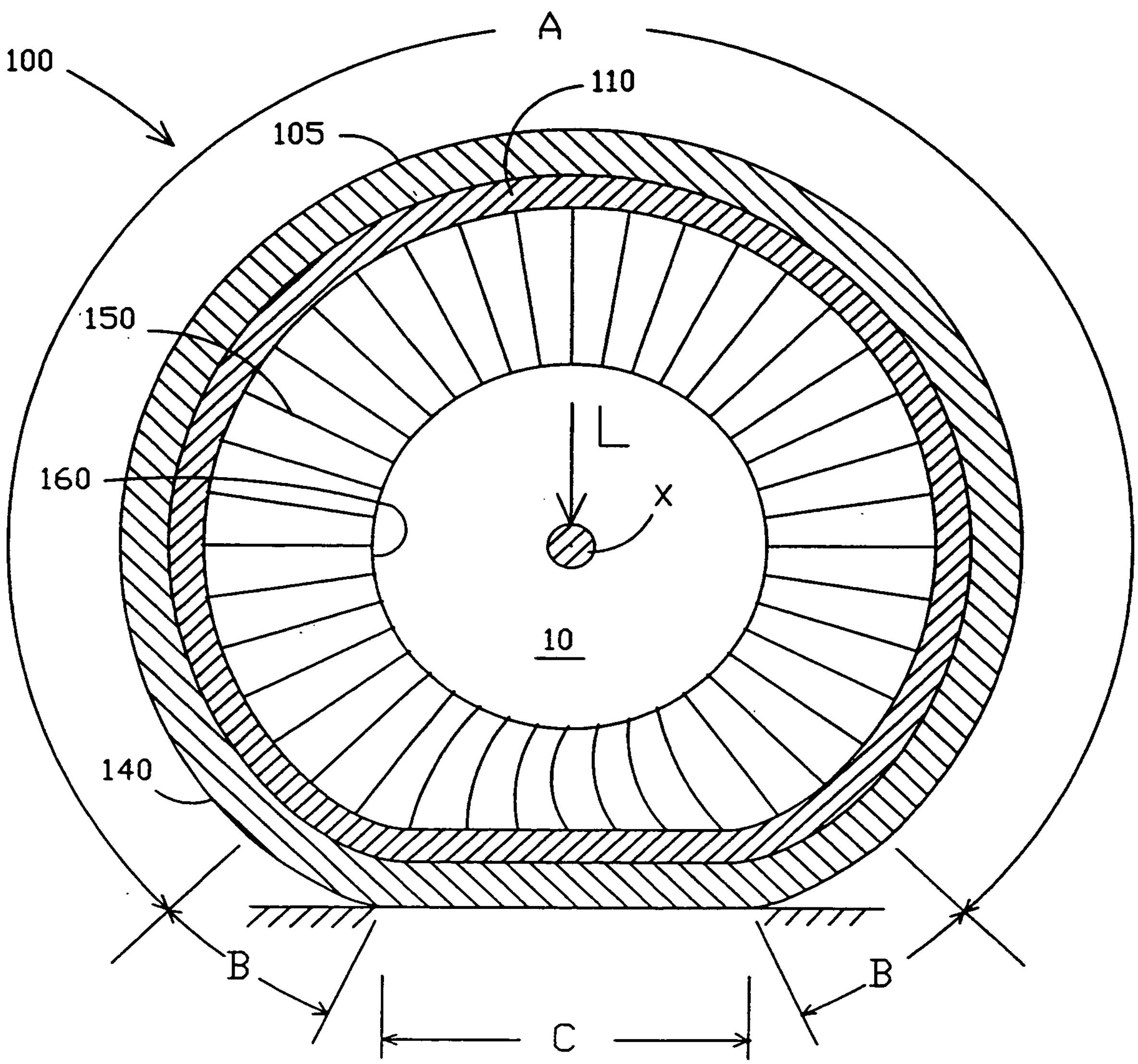
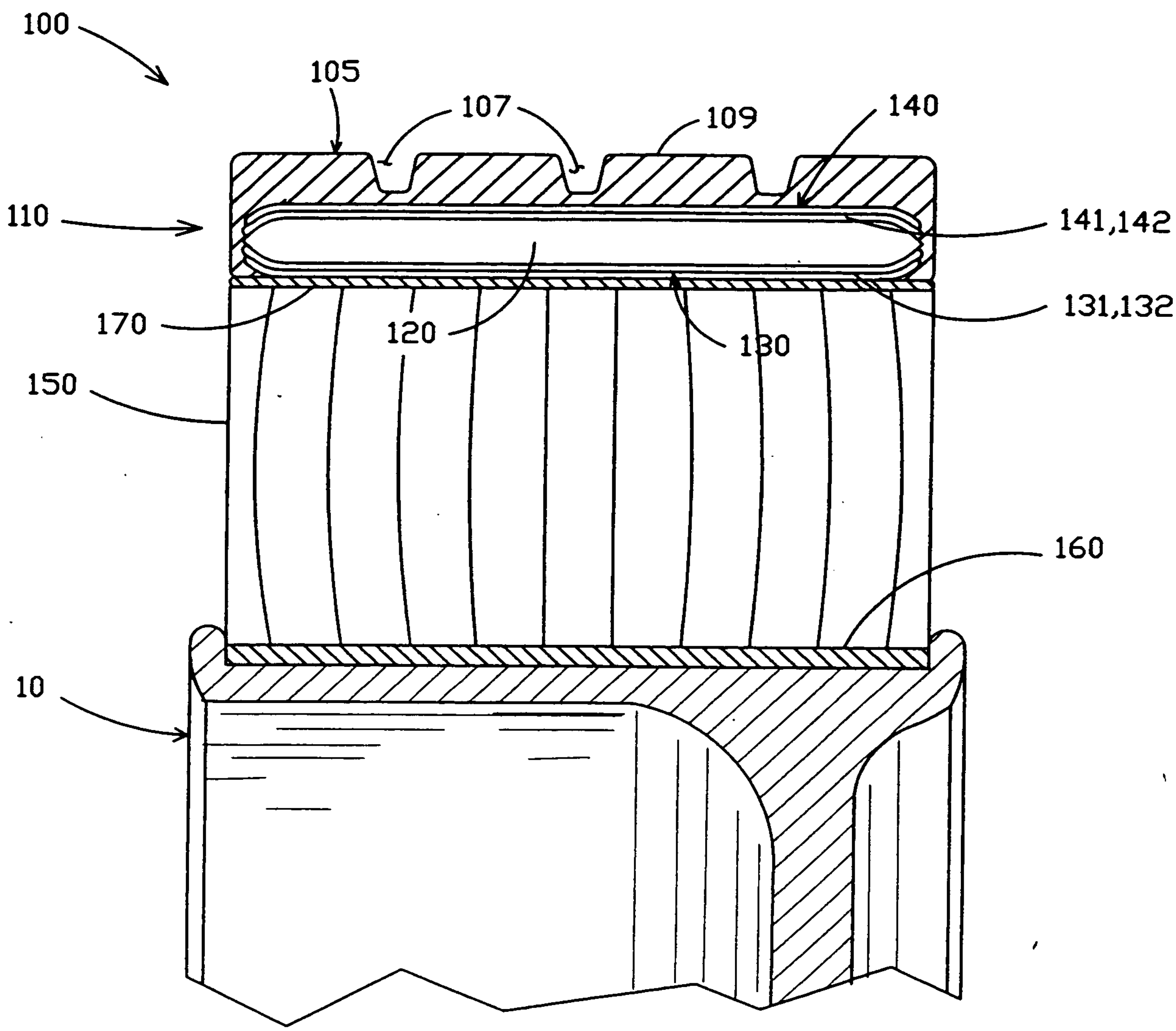


Fig. 2



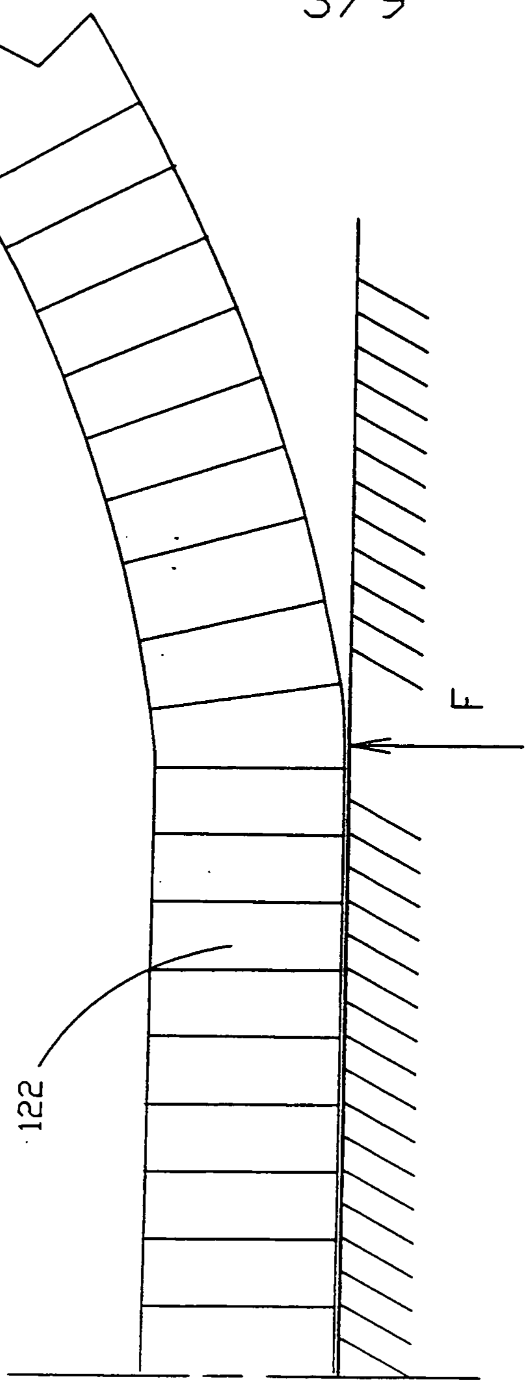


Fig. 3

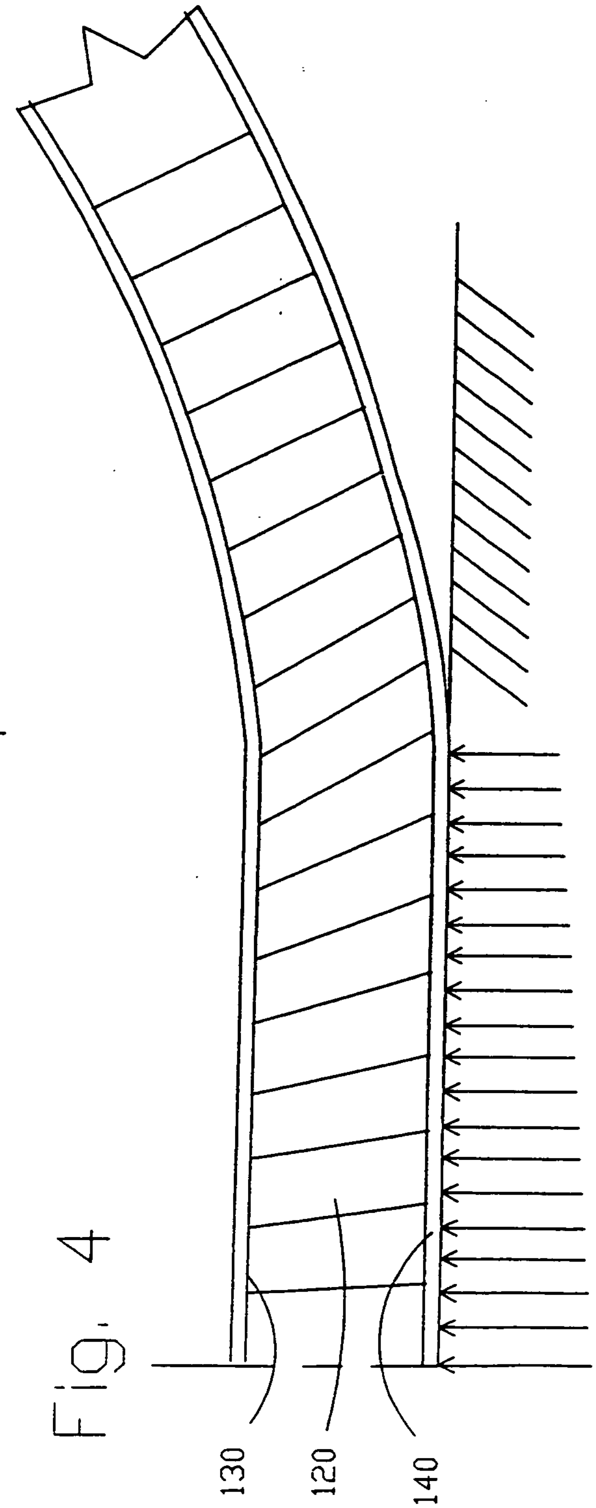


Fig. 4

Fig. 5

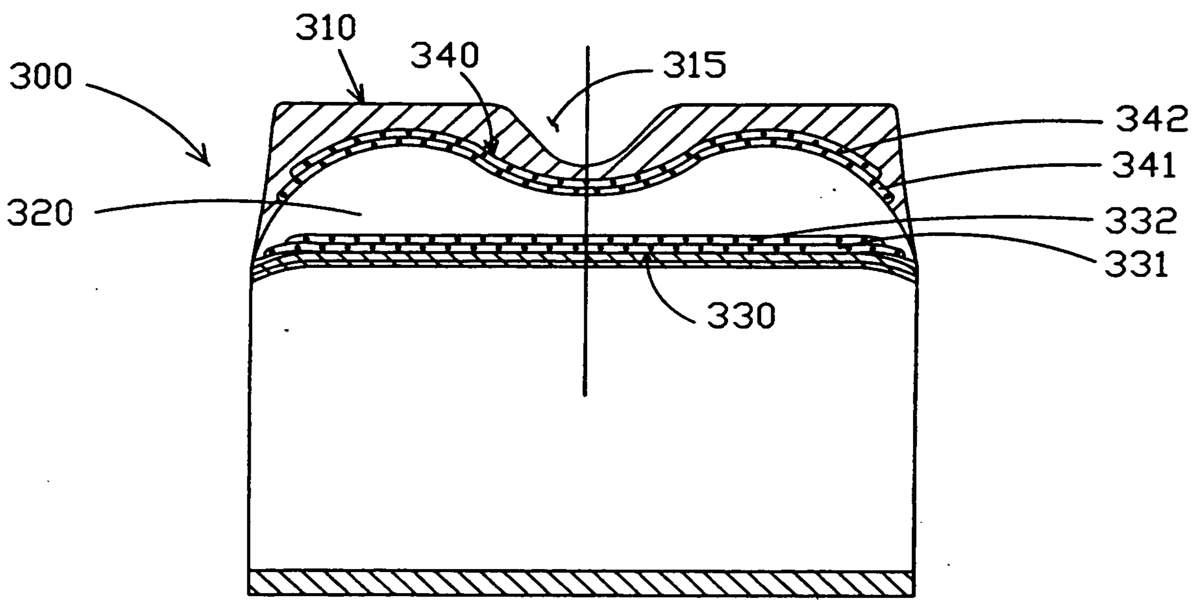


Fig. 6

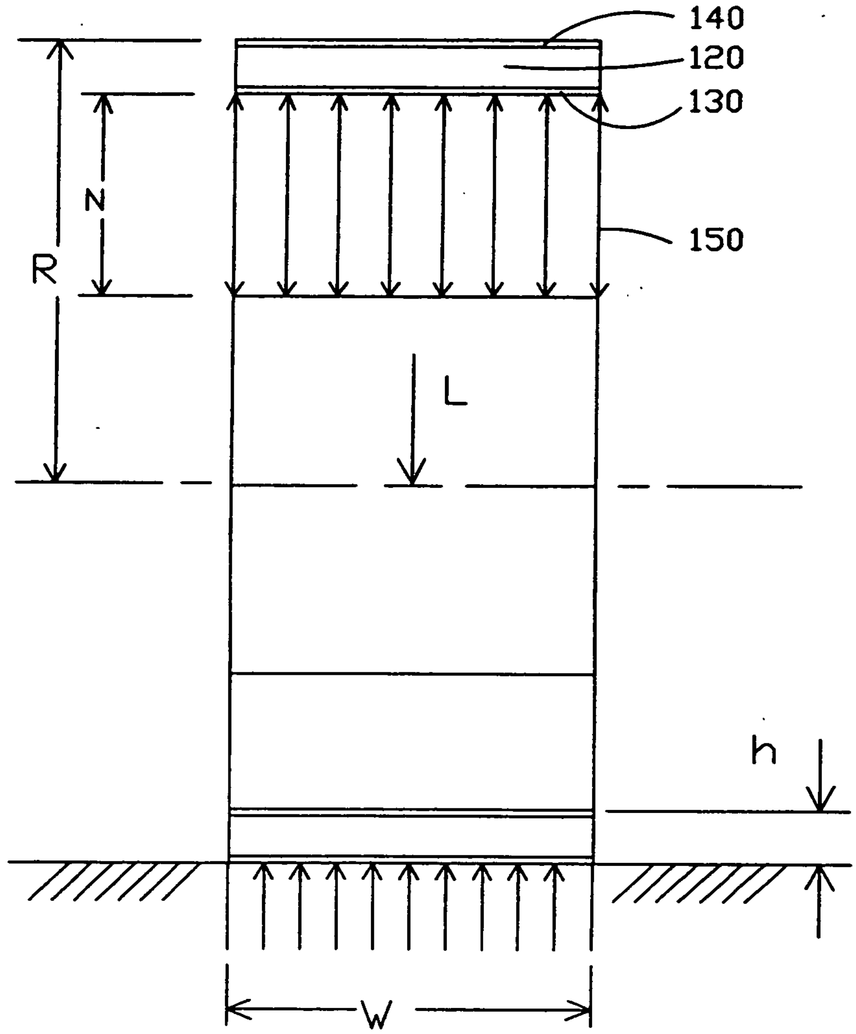


Fig. 7

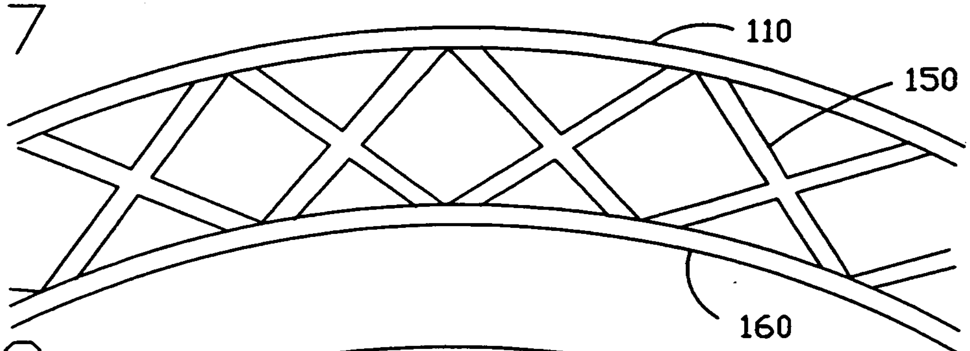


Fig. 8

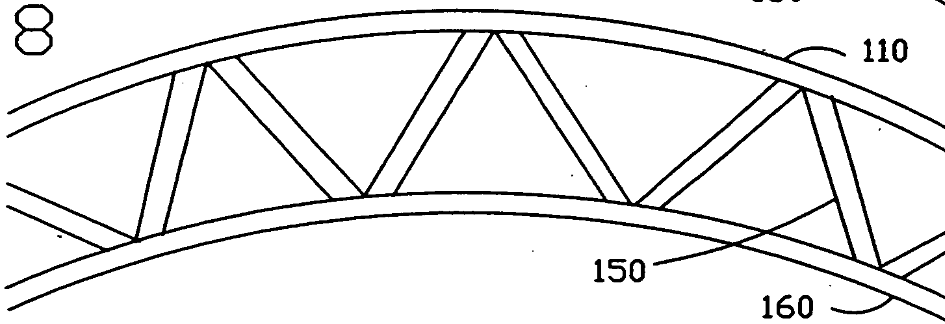


Fig. 9

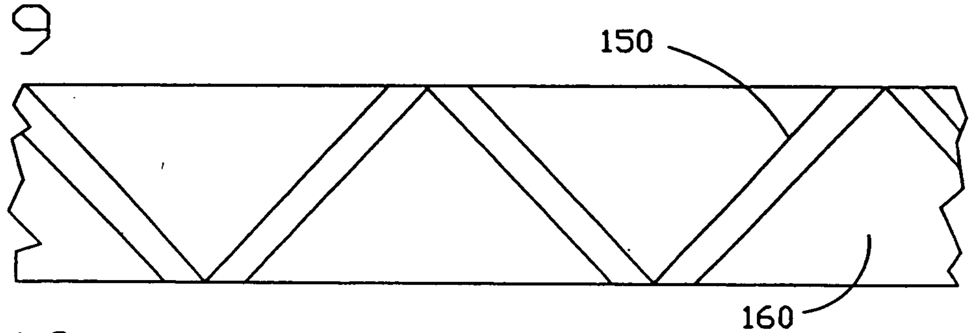


Fig. 10

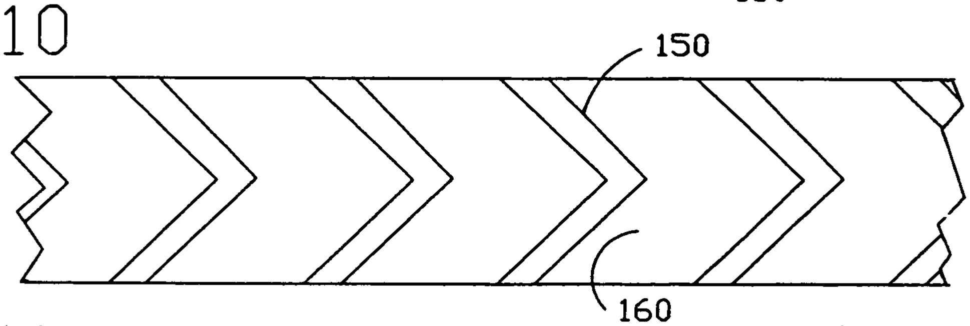


Fig. 11

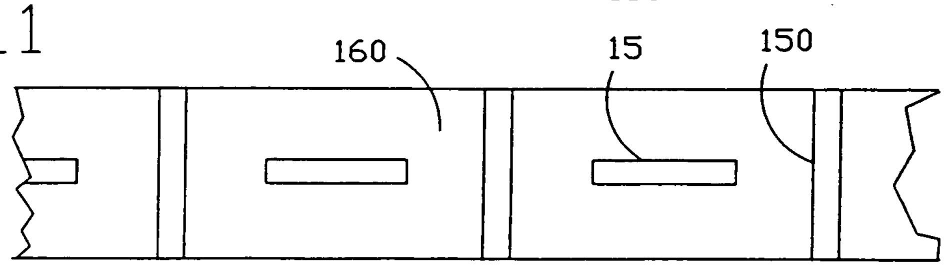
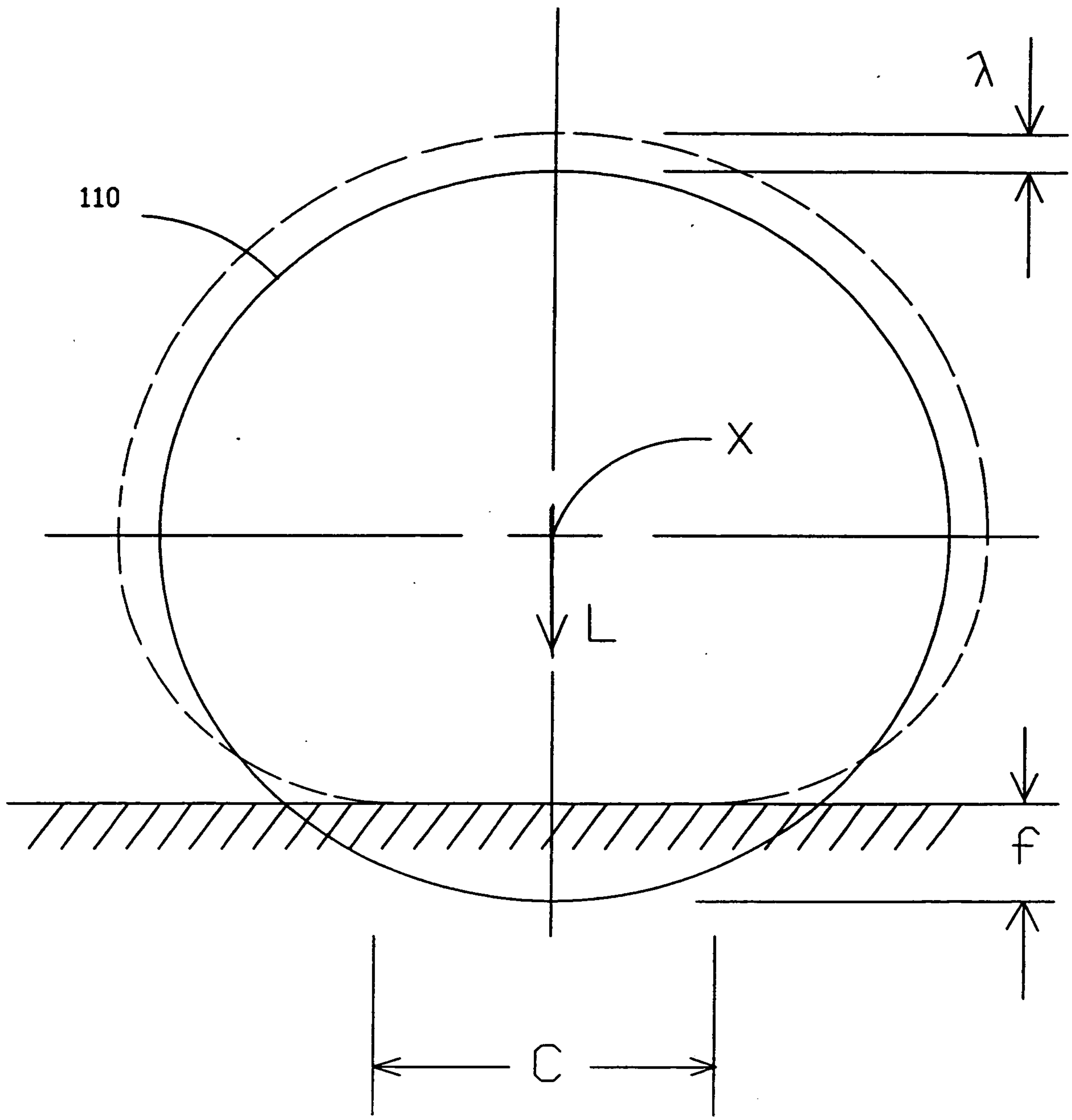
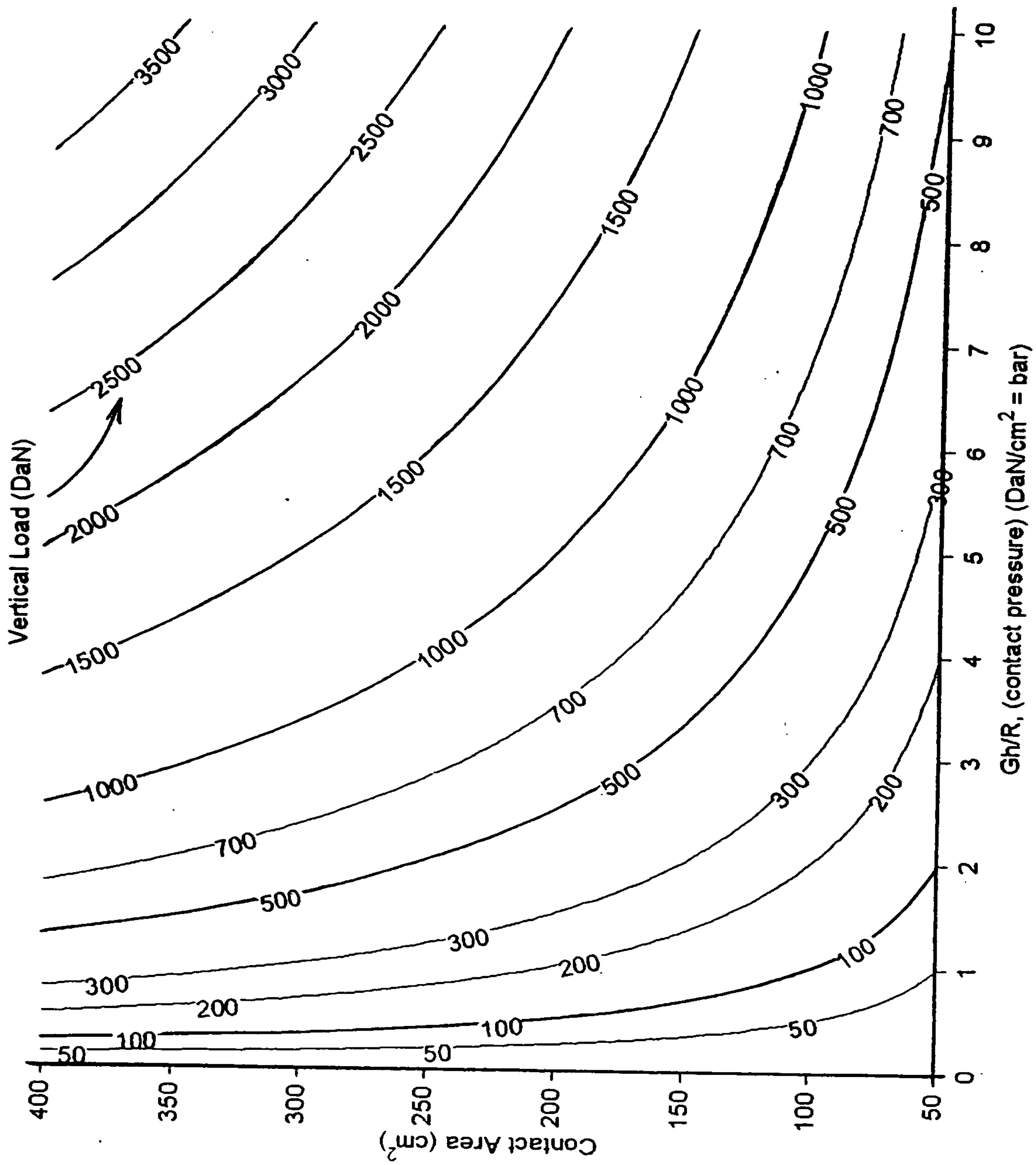


Fig. 12





Vertical Load (DaN)
Gh/R, (contact pressure) (DaN/cm^2 = bar)
Contact Area (cm^2)
3500
3000
2500
2000
1500
1000
700
500
300
200
100
50

Fig. 13

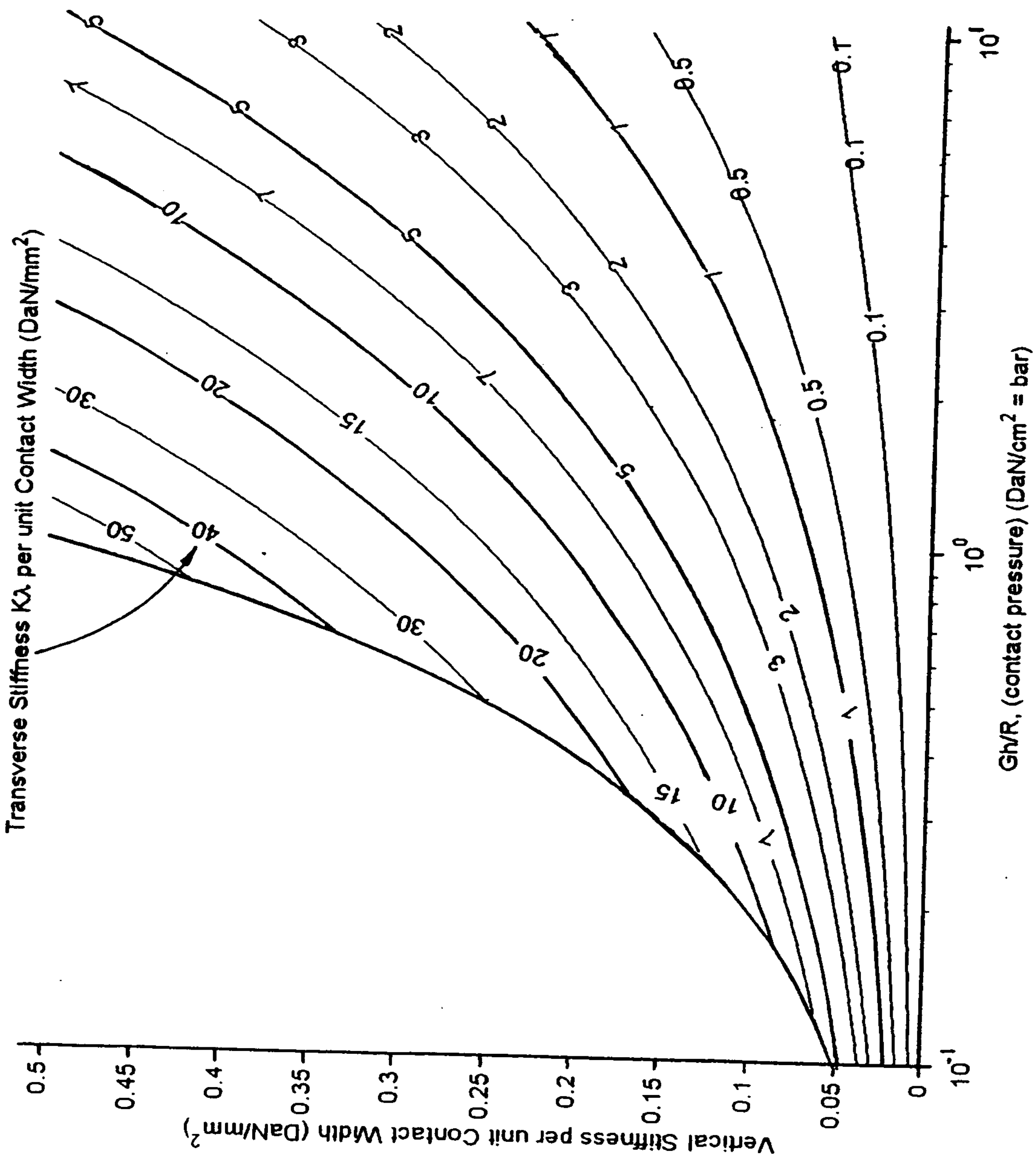

Transverse Stiffness Kλ per unit Contact Width (DaN/mm²)
Vertical Stiffness per unit Contact Width (DaN/mm²)
Gh/R, (contact pressure) (DaN/cm² = bar)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
10⁻¹
10⁰
10¹
50
40
30
20
15
10
7
5
3
2
1
0.5
0.1

Fig. 14